Crop Productivity and Economics during the Transition to Alternative Cropping Systems

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ABSTRACT

Many environmental benefits accrue from reducing tillage and increasing crop diversity; however, economic factors often encourage the continued use of intensive tillage and specialized crop production. This study examined crop yields, input costs, and economic returns during the transition to a range of cropping system alternatives in the northern Corn Belt region, including different system (organic, conventional), tillage (conventional, strip-tillage), rotation (corn–soybean, corn–soybean–wheat/alfalfa–alfalfa) [*Zea mays* L., *Glycine max* (L.) Merr., *Triticum aestivum* L., *Medicago sativa* L.], and fertility (no fertilizer/manure, fertilizer/manure applied at recommended rates) treatments. Increasing crop diversity and reducing tillage intensity reduced total costs by \$24–102 ha^{-1} within conventional treatments, and \$16–107 ha^{-1} within organic treatments. Yields of corn, soybean, and wheat were more than 15% lower when using organic vs. the highest yielding conventional practices. Treatments receiving fertilizer or manure had wheat yields more than 0.3 Mg ha^{-1} and alfalfa yields 2.7 Mg ha^{-1} higher than treatments that did not receive fertilizer or manure. Within conventional systems, no significant differences in the 4-yr net present value of net returns were detected for tillage and rotation alternatives. Net present values for the organic systems without organic price premiums were at least \$692 ha^{-1} lower than for the best conventional systems suggesting a barrier to the adoption of these systems should organic price premiums decline. However, when organic price premiums were included, most organic treatments had net present values comparable to or exceeding those from conventional treatments.

Many environmental benefits accrue from reducing tillage intensity and increasing crop diversity (National Research Council, 1993); however, economic factors often encourage the continued use of intensive tillage and specialized crop production (Uri, 1999; National Research Council, 1993). The adoption of less intensive tillage systems in the northern Corn Belt has been slow over the last decade; although recently there has been an increase in the use of reduced tillage coinciding with increasing energy costs (CTIC, 2006). Crop diversity has also declined in this region. In Minnesota, for example, the portion of cropland devoted to corn and soybean production in Minnesota increased steadily since the early 1900s, reaching 73% of the harvested area in 2005, with concurrent reductions in hay and small grains (USDA-NASS, 2006). While most farmers recognize the need to protect natural resources, management decisions, often of necessity, are driven by concern for economic survival.

Organic crop production, which depends on crop rotations to maintain productivity, represents one set of production alternatives that may be both environmentally sound and economically viable. Organic production has historically represented a small portion of the total cropland in Minnesota; although, it has more than doubled from 22 783 ha in 1997 to 46 749 ha in 2003 (USDA-ERS, 2006). Producers adopt organic production systems for many reasons; however, the decision is at least partially driven by the potential for increasing farm profitability due to the price premiums offered for certified organic crops (Mahoney et al., 2004; Dobbs and Smolik, 1996; Welsh, 1999). A criticism of organic systems, however, is their heavy reliance on tillage for weed control (Trewavas, 2001). As tillage increases, the risk for erosion and loss of soil organic matter (Lal, 1997; Reicosky, 1997) also increases, which has stimulated research into ways to reduce tillage use in these systems (Porter et al., 2005).

Within conventional production systems, there are opportunities to increase farm profitability by reducing tillage and increasing crop diversity, particularly with a scenario of rising energy costs (Meyer-Aurich et al., 2006). Reducing tillage and increasing crop diversity can reduce production costs by decreasing fuel and labor use, and decreasing use of energy intensive fertilizer and pesticide inputs (DeVuyst et al., 2006). However, reducing tillage or increasing crop diversity alone may cause tradeoffs between machinery related costs and pesticide or fertilizer inputs (Archer et al., 2002; Klemme, 1985; Zentner et al., 2002a,2002b). Reducing production costs may also lead to yield reductions, negating any cost savings and reducing profitability (DeVuyst et al., 2006).

For both organic and conventional production systems, the transition from an existing system to an alternative production system can give rise to economic obstacles that prevent adoption even if they would be viable in the long-run. As producers learn how to manage new systems during the transition period, biological changes and management adjustments may increase input costs or depress yields (Jaenicke and Drinkwater, 1999; Dabbert and Madden, 1986; Zentner et al., 2002b), inhibiting adoption of these systems in the short-term (Jolly et al., 1983; Krause and Black, 1995). A few studies have examined short-term effects on crop yields and input costs during the transition period to organic systems (Jaenicke and Drinkwater, 1999; Hanson et al., 1997; Dabbert and Madden, 1986); however, there is a need for studies that examine the transition effects over a wider range of alternative production systems.

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To address these needs, a long-term cropping systems field study was initiated in 2002 in Minnesota to investigate the agronomic, environmental, and economic performance of a wide range of cropping systems. Our hypothesis was this: systems that reduce tillage, increase crop diversity, and reduce use of purchased inputs can improve overall sustainability by increasing economic returns, reducing greenhouse gas emissions, and enhancing soil quality, while maintaining adequate weed control, soil fertility, and crop productivity. The objective of this study was to determine the effects of adopting alternative production systems on input costs, crop yields, and economic returns during the transition period. As such, the focus is limited to short-term consequences, with longer-term impacts left to future study.

MATERIALS AND METHODS

Field Study

A long-term cropping systems field study was established in 2002 at the Swan Lake Research Farm located near Morris, MN (45° 41′ N, 95° 48′ W, elevation 370 m). Annual precipitation in this region averages 645 mm and average monthly temperatures range from −13.1°C in January to 21.7°C in July (NOAA-NCDC, 2002). Average corn growing season growing degree days at the site is 1204°C (base 10°C). Five soil series were identified within the experimental site (USDA-SCS, 1971): Barnes loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll), Flom silty clay loam (fine-loamy, mixed, superactive, frigid Typic Endoaquoll), Hamerly clay loam (fine-loamy, mixed, superactive, frigid Aeric Calciaquoll), Parnell silty clay loam (fine, semectitic, frigid Vertic Argiaquoll), and Vallers silty clay loam (fine-loamy, mixed, superactive, frigid Typic Calciaquoll).

The experimental design is a split-plot randomized complete block with four replications. Two system treatments: conventional (CNV) and organic (ORG) were randomly assigned as main plots. Split-plot treatments consisted of combinations of two primary tillage treatments: conventional tillage (CT) and strip tillage (ST); two rotations: corn–soybean (C-S) and corn–soybean–spring wheat/alfalfa–alfalfa (C-S-W/A-A); and two fertility treatments: no added fertilizer or manure (NF), and fertilizer or manure applied at recommended rates (YF). For the YF treatments, fertilizer was applied to CNV treatments and manure was applied to the ORG treatments. The experimental design included all phases of each crop rotation each year, employing 192 plots (6 by 12 m each). Before initiating the study, the area was uniformly cropped with soybean to minimize residual effects of previous treatments. Historically, the site had been cropped in a corn–soybean–spring wheat rotation under CT.

A summary of the operation sequences for each treatment combination is given in Table 1. Primary tillage in the CT treatments consisted of moldboard plow following corn or alfalfa, and chisel plow following soybean. Field cultivation was used for seedbed preparation in the spring before planting under the

Table 1. Typical schedule of field operations for each treatment.

Crop	Timing	Operation	CNV† CT	ORG CT	CNV ST	ORG ST
Corn	Nov.	Moldboard plow (after alfalfa) or chisel plow (after soybean)	X	X		
	Nov.	Strip tillage			X	X
	Apr.	Manure application (YF only)		X		X
	Apr.	Field cultivation (2x after alfalfa)	X	X		
	Apr.	Strip tillage (C-S-W/A-A only)				X
	May	Plant corn	X	X	X	X
	May-June	Rotary hoe (2–3 x's)		X		X
	June	Herbicide application	X		X	
	June-July	Row cultivation (1–3 x's)		X		X
	June	Fertilizer application (YF only)	X		X	
	June	Broadcast rye seed (C-S only)		X		X
	June-July	Mow between rows (0–6 x's, C-S-W/A-A only)				X
	June-July	Herbicide application	X		X	
	Oct.	Harvest	X	X	X	
Soybean	Nov.	Moldboard plow	X	X		
	Nov.	Strip tillage			X	X
	May	Field cultivation	X	X		
	May	Plant soybean	X	X	X	X
	May-June	Rotary hoe (2–4 x's)		X		X
	June	Herbicide application	X		X	
	June	Mow between rows				X
	June-July	Row cultivation (1–3 x's)		X		X
	June-July	Herbicide application	X		X	
	July	Mow between rows (0–2 x's)				X
	July	Insecticide application	X		X	
	July-Aug.	Limited hand weeding		X		X
	Sep.	Harvest	X	X	X	X
Wheat	Nov.	Chisel plow	X	X		
	Apr.	Fertilizer application (YF only)	X		X	
	Apr.	Manure application (YF only)		X		X
	Apr.	Field cultivation	X	X		
	Apr.	Plant (wheat and alfalfa in CNV or wheat in ORG)	X	X	X	X
	May	Harrow		X		X
	May	Broadcast alfalfa seed		X		X
	May	Harrow		X		X
	Aug.	Harvest	X	X	X	X
Alfalfa	June	Mow, rake, bale	X	X	X	X
	July	Mow, rake, bale	X	X	X	X
	Aug.	Mow, rake, bale	X	X	X	X

† CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates; NF, no added fertilizer or manure.

CT treatments. Primary tillage in the ST treatments consisted of strip-tillage in the fall before spring-seeded corn or soybean. The strip tillage implement tills a strip 0.1 m wide and to a depth of 0.2 m. Corn and soybean are planted into the tilled strips in spring. No tillage was used before planting spring wheat under the ST treatment. In the ORG systems, weed control in corn and soybean included the in-crop use of a rotary hoe early in the season followed by inter-row cultivation until canopy closure. A flex-tine harrow was used for weed control in spring wheat in the ORG system. Timing of weed control operations in the ORG system was determined using the WeedCast decision aid (Archer et al., 2006; Oriade and Forcella, 1999). To minimize tillage while maintaining some degree of weed control in the ORG ST treatments, mowing between the rows was used periodically on corn or soybean in addition to or in place of one or more inter-row cultivation operations (e.g., Donald et al., 2001). For the field plot study, a push lawn mower was used for mowing between the rows. Although a commercial mower is not available for mowing between the rows of a standing crop, a between-row mower has been developed by local organic farmers for this purpose, so this operation is feasible on a field scale. A limited amount of hand weeding was also used in the ORG soybean plots, as is common with local organic production practices. The time spent hand weeding was recorded for use in estimating input costs. In the CNV systems, herbicides were applied for weed control as needed. Because of the complexity of the management systems, weed seed production was used as a single measure of weed abundance across all treatments. Seeds were measured by vacuuming all seeds from the soil surface in a 6-cm diam. circle at 20 locations along a diagonal transect across each plot. Vacuuming was performed in late autumn after the last crop (corn) was harvested, but before autumn tillage. Seeds were counted by species and expressed on a square-meter basis.

In the CNV system, seeding rates were 74,000 seeds ha^{-1} for corn, and 561,000, 405,000, 405,000, and 430,000 seeds ha^{-1} for soybean in 2002, 2003, 2004, and 2005, respectively. In the ORG system, seeding rates were 82,000 seeds ha^{-1} for corn, and 561,000 and 498,000 seeds ha^{-1} for soybean in 2002 and 2003–2005, respectively. In both the CNV and ORG systems, seeding rates for wheat were 134 kg ha^{-1} in 2002–2003, and 148 kg ha^{-1} in 2004–2005, and the seeding rate for alfalfa was 13.4 kg ha^{-1} in all years. 'Wrangler' alfalfa was grown all years, 'Alsen' wheat was grown in 2002–2004, and 'Oklee' wheat was grown in 2005. Corn and soybean varieties changed from year to year as newer varieties became available. Soybean relative maturity groups ranged from 0.7 to 1.3 in the CNV system and 0.9 to 1.1 in the ORG system. Corn relative maturity ratings ranged from 93 to 94 d in the CNV system and 94 to 95 in the ORG system. In the CNV system, glyphosate-resistant soybean varieties were used each year; a Bt (*Bacillus thuringiensis*) corn variety was grown in 2002, and corn varieties with both glyphosate-resistance and Bt traits were planted in 2003–2005.

In the ORG system, nongenetically modified, nontreated seeds were used for all crops, with clear-hilum soybean varieties planted each year. Certified organic seed was used for the ORG treatments in 2004–2005. ORG and CNV treatments were planted at the same time, with the exception of alfalfa. Alfalfa was planted simultaneously with the wheat in the CNV treatments, but it was planted using a broadcast spreader just before the second harrow operation after wheat emergence in the ORG treatments. A rye (*Secale cereale* L.) cover crop was seeded into corn in the ORG C-S treatments using a broadcast spreader before the second inter-row cultivation operation to meet nominally the minimum rotation requirements for organic certification. 'Rymin' rye was planted at rates of 67 kg ha^{-1} in 2002, 122 kg ha^{-1} in 2003, 152 kg ha^{-1} in 2004 and 2005, and a portion of the plots were replanted in 2004 following corn harvest at a rate of 140 kg ha^{-1} due to poor stand establishment.

Fertilizer was applied to the CNV YF treatments at rates equivalent to 78–15–28 kg ha^{-1} of N-P-K before planting wheat; and 11–17 kg ha^{-1} of N-P at planting for corn and soybean. Additional N was applied in late June or early July to CNV C-S YF corn based on preplant soil N tests and using the ARS Nitrogen Decision Aid (Olness et al., 1999). Sidedress N application rates were 175, 100, 139, and 128 kg ha^{-1} in 2002, 2003, 2004, and 2005, respectively. Solid dairy manure was applied to the ORG YF treatments at a rate of 16,800 kg ha^{-1} (wet weight) before planting corn in 2002; liquid swine manure at a rate of 37,400 L ha^{-1} (125–29–124 kg ha^{-1} N-P-K) was applied following soybean in the fall of 2002; and solid dairy manure was applied following soybean at a rate of 22,900 kg ha^{-1} for C-S (112–15–105 kg ha^{-1} N-P-K in 2005) and 37,200 kg ha^{-1} for C-S-W/A-A (182–25–170 kg ha^{-1} N-P-K in 2005) in the spring of 2004 and 2005. Nutrient content of the manure applied in the spring of 2002 and 2004 was not measured due to problems with the sample processing procedure. Manure application rates were planned to avoid excess application of P and K, which resulted in lower N applied in the ORG C-S treatments compared to the CNV C-S treatments.

Yield samples for corn, soybean and wheat grain were measured from a central strip within each plot. Corn, wheat, and soybean were harvested with a plot combine using 1.5 m wide headers appropriate for each crop. Yields were adjusted to moisture contents of 155, 130, and 135 g kg^{-1} for corn, wheat and soybean, respectively. The remaining plot area was harvested with a field-scale combine after yield samples were collected. Yields for alfalfa hay were measured using two 0.5 m^2 hand-harvested samples per plot at each of three harvest dates through the year and were adjusted to a moisture content of 150 g kg^{-1}. The remaining alfalfa was mowed, raked, baled, and removed from the plots using field-scale equipment after yield samples were collected.

Economic Analysis

Costs for each production system were estimated using the Cost and Returns Estimator (CARE) (USDA-NRCS, 1993) based on the operations and inputs used for each treatment each year. Machinery ownership costs were estimated outside of CARE following American Agricultural Economics Association guidelines (Eidman et al., 1998) and based on equipment sized for a representative farm of 398 ha. This farm size represents the average harvested cropland per farm for Stevens County, Minnesota, in 2002 (USDA-NASS, 2004). Machinery costs were based on Minnesota Extension Service estimates (Lazarus and Selley, 2005). Fertilizer costs were from the USDA-National Agricultural Statistics Service (USDA-NASS, 2005), and herbicide costs were from North Dakota State University Extension Service estimates (NDSU, 2005).

A fuel cost of \$0.66 L^{-1} was used for this analysis and an additional 15% for lubricants was assumed. Drying costs were calculated in CARE for corn, soybean, and wheat based on observed harvest moistures. We assumed the crops would be dried to the moisture levels specified above, using liquefied petroleum (LP) gas, and used an LP cost of \$0.37 L^{-1}. A wage rate of \$11.00 h^{-1} was used in calculating labor costs.

Manure can represent a substantial cost to organic producers and can vary widely depending on transport distances and the costs of obtaining the manure. Based on USDA-Economic Research Service estimates (Ribaudo et al., 2003), a cost of \$6.61 Mg^{-1} for solid manure and \$1.36 m^{-3} for liquid manure was used to represent mixing, loading and transporting costs within 1.6 km of the field. Application costs were estimated in CARE based on the tractors and implements used for application. No cost was included for purchasing the manure, assuming the manure was either produced within the farm or was freely available from a neighboring farm.

The organic and conventional prices used in the analysis are shown in Table 2. To isolate production-related effects from market effects, average prices for the period 1995 to 2003 were used in calculating crop revenues. Market year average prices for Minnesota (USDA-NASS, 2006) were used for conventional crops, and organic prices for the upper Midwest (Streff and Dobbs, 2004) were used for organic crops. The effect of government loan deficiency payments was included in the values shown in Table 2, using 2005 commodity loan rates for Stevens County, Minnesota (USDA-FSA, 2004, 2005). Loan deficiency payments for 1995 to 2003 were calculated as the difference between the loan rate and the market year average price for each year. If the loan rate was less than the market year average price, the loan deficiency payment was zero. The average loan deficiency payment for the period 1995 to 2003 was added to both the conventional and organic average crop prices.

With recent increases in demand for organic dairy products, a market for organic alfalfa is emerging; however, prices are not yet well established. For this analysis, it was assumed an organic price premium was not available for alfalfa. Crop revenues were calculated by multiplying the prices by the observed yields. For the ORG system, conventional prices were used in 2002 and 2003, and organic prices were used in 2004 and 2005 reflecting the minimum waiting period for organic certification during the transition from conventional crop production. The estimated costs for each year were subtracted from the calculated revenue to obtain net returns to land and management for each crop in each treatment each year. The net present value of the 2002 to 2005 net returns was calculated using a discount rate of 6%. Net present value analysis was chosen for this project because it incorporates both the timing and magnitude of net returns. This may be important in transitioning to new systems where returns may be changing over time, and particularly for organic systems, where net returns may dramatically increase after certification. While this approach is suitable for analyzing the short-term performance of these systems, it is important to recognize that the ultimate economic viability of these systems also depends on long-term performance, and that uncertainty about future returns can also act as an economic barrier to adoption (Kuminoff and Wossink, 2005). Analysis of the longer-term performance and uncertainty effects is beyond the scope of this study.

Statistical Analysis

Crop yields and net present values were analyzed using the Mixed Procedure of SAS (SAS Institute, 2006). System, tillage, fertility, rotation, and their interactions were considered fixed effects. For analyzing average yields and net present values over the four transition years, blocks and years were considered random effects. To capture any yield trends that occurred during the transition period, a separate model was estimated using the method suggested by Loughin et al. (2007) to analyze potential year and year by treatment effects assuming a linear annual yield trend. This model incorporated linear year interactions with the system, tillage, fertility, rotation effects and their interactions as fixed effects. Blocks, system, tillage, fertility, rotation and year and appropriate interactions were included as random effects. Multiple comparison tests for differences among yields and net present values were identified using the Tukey–Kramer adjustment and a significance level of $P = 0.05$.

Table 2. Conventional and organic crop prices including government loan deficiency payments.†

Crop	Conventional price	Organic price
	$\$ Mg^{-1}$	
Corn	86.23	161.04
Soybean	210.58	522.22
Spring wheat	130.46	223.07
Alfalfa hay	84.53	84.53

† Source: Conventional prices from USDA-NASS (2006) and organic prices from Streff and Dobbs (2004) adjusted for county loan rates from USDA-FSA (2004, 2005).

RESULTS AND DISCUSSION

Production Costs

With the exception of the ORG C-S-W/A-A treatments, average total costs for the ST treatments were \$16–26 ha^{-1} lower than for their CT counterparts (Table 3). This was largely due to reductions in machinery ownership costs. In the CNV system, the ST treatments resulted in a \$5 ha^{-1} reduction in diesel fuel costs, compared to CT. The reduction in fuel costs was largely offset by increases in herbicide costs, and in some cases, by increased crop drying costs, even though planting dates were the same for ST and CT treatments. In the ORG system, the ST treatments did not reduce fuel costs since the fuel saved in reducing primary tillage was offset by increased use of secondary tillage and mowing for weed control. Seed, fertilizer, and chemical costs were \$5–74 ha^{-1} lower for the ORG treatments than for their CNV counterparts; however, this cost reduction was offset by the cost of manure handling and loading, and added diesel fuel and labor costs for field operations. As a result, total operating costs for the ORG C-S treatments were \$11–19 ha^{-1} higher than for the CNV C-S treatments, and total operating costs for C-S-W/A-A treatments were roughly the same for ORG systems and CNV systems. The ORG treatments required 30 to 140% more labor than the CNV treatments reflecting the use of limited hand weeding and the additional field trips for mechanical weed control in the ORG treatments, which were only partially offset by labor required for chemical applications in the CNV treatments. Machinery ownership costs were \$7–51 ha^{-1} higher for the ORG treatments than their CNV counterparts due to the need for additional machinery, resulting in \$5–59 ha^{-1} higher total costs for the ORG treatments than for the CNV treatments. Total costs for the C-S-W/A-A treatments were \$11–57 ha^{-1} lower than for the C-S treatments across all system, tillage, and fertility treatments with the exception of the ORG ST NF treatments. Increasing crop diversity and reducing tillage intensity reduced total costs by \$24–102 ha^{-1} within conventional treatments, and \$16–107 ha^{-1} within organic treatments.

Yields

Corn yields, over the 4-yr transition period, were affected by system, fertility, tillage, and five interactions: system by fertility, fertility by rotation, system by tillage, tillage by rotation, and system by tillage by rotation

Table 3. Average production costs for treatments averaged over years 2002 to 2005.†

	CNV								ORG							
	CT				ST				CT				ST			
	C-S		C-S-W/A-A		C-S		C-S-W/A-A		C-S		C-S-W/A-A		C-S		C-S-W/A-A	
	YF	NF	YF	NF	YF	NF	YF	NF	YF	NF	YF	NF	YF	NF	YF	NF
Operating costs	$ ha^{-1}															
Drying	44	33	28	22	48	37	27	22	34	26	23	20	36	27	20	19
Diesel	25	25	26	26	20	20	21	21	35	34	32	31	36	34	32	31
Labor	14	13	22	22	13	12	21	20	28	27	29	29	30	29	34	33
Seed, fert., chem	190	125	137	96	194	135	145	106	120	120	82	82	120	120	80	84
Manure haul & load	–	–	–	–	–	–	–	–	58	–	41	–	58	–	41	–
Other operating‡	38	36	39	37	34	31	34	32	48	44	43	41	48	44	44	42
Total operating cost	311	232	252	202	309	234	248	202	322	251	250	203	328	255	251	210
Machinery ownership	183	181	202	199	162	159	180	177	194	190	209	206	172	169	231	228
Total cost	495	413	454	402	471	393	428	379	516	441	459	409	500	423	482	438

† CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates; NF, no added fertilizer or manure.
‡ Includes machinery repairs and maintenance, insurance, interest on operating capital.

($P < 0.05$). Average corn yield over the 4-yr transition period was 0.5 to 6.9 Mg ha^{-1} higher for the CNV CT C-S YF treatment than for other treatments, but not significantly higher than yields obtained under four other CNV system treatments (Table 4): CNV CT C-S-W/A-A YF and NF, CNV ST C-S YF, and CNV ST C-S-W/A-A YF. The CNV CT C-S YF treatment represents the most common cropping system in the region. Average corn yield for the CNV CT C-S YF treatment was significantly greater than yields obtained under any of the ORG treatments, with the best ORG treatments showing a 34% reduction in average corn yield in comparison. This yield reduction was greater than that reported by Porter et al. (2003) for a comparable study in southwestern Minnesota, and contrary to the findings of Delate and Cambardella (2004), which showed no yield reduction for organic vs. conventional corn production during the transition years in Iowa. The low nutrient content and/or availability of the applied manure may have contributed to the yield reduction in the organic treatments relative to those in the CNV treatments and the organic treatments of Delate and Cambardella (2004). Manure application rates in the current experiment were based on higher estimated nutrient contents, which resulted in lower-than-planned applied nutrients.

Average soybean yields were affected by system, fertility, tillage, system by rotation interaction, and system by tillage interaction ($P < 0.05$). Soybean yields were not significantly different among the CNV treatments, the ORG CT C-S YF treatment, and the ORG CT C-S-W/A-A YF treatment. Significant soybean yield declines occurred for the other ORG treatments, with the largest declines occurring under the ORG ST C-S-W/A-A YF and NF treatments compared to CNV CT C-S YF. Although the yield reduction was not significant, the relative yields for the ORG CT C-S YF and ORG CT C-S-W/A-A YF treatments were 85% and 81% of the average yield for the CNV CT C-S YF treatment. These values are somewhat comparable to the levels of 59% and 84% observed by Porter et al. (2003) for similar treatments, and they are consistent with Delate and Cambardella (2004), who showed no significant reduction in soybean yield in organic systems compared to conventional systems during the transition years. Although, bean leaf beetles [*Cerotoma trifurcata* (Forster)], which have been linked to soybean staining (Krell et al., 2003), were ob-

Table 4. Crop yields by treatment averaged over years 2002 to 2005.†

System	Tillage	Rotation	Fertility	Corn		Soybean		Wheat		Alfalfa	
				Mg ha^{-1}							
CNV	CT	C-S	YF	10.0	a‡	2.7	a				
CNV	CT	C-S	NF	7.6	bcd	2.2	abcde				
CNV	CT	C-S-W/A-A	YF	9.5	ab	2.7	a	3.2	a	9.7	a
CNV	CT	C-S-W/A-A	NF	8.4	abc	2.4	abc	2.4	cd	7.0	b
CNV	ST	C-S	YF	9.3	ab	2.5	ab				
CNV	ST	C-S	NF	6.8	cde	2.3	abcd				
CNV	ST	C-S-W/A-A	YF	8.4	abc	2.6	ab	3.0	ab	9.9	a
CNV	ST	C-S-W/A-A	NF	7.5	bcd	2.4	abc	2.3	cde	7.2	b
ORG	CT	C-S	YF	6.6	cde	2.3	abcd				
ORG	CT	C-S	NF	5.0	efg	1.9	cdef				
ORG	CT	C-S-W/A-A	YF	6.6	cde	2.2	abcde	2.6	bc	7.3	b
ORG	CT	C-S-W/A-A	NF	6.5	cde	2.1	bcde	1.9	de	6.3	b
ORG	ST	C-S	YF	5.9	def	1.9	cdef				
ORG	ST	C-S	NF	4.4	fg	1.8	def				
ORG	ST	C-S-W/A-A	YF	3.2	g	1.4	f	2.0	de	7.8	ab
ORG	ST	C-S-W/A-A	NF	3.1	g	1.6	ef	1.7	e	6.7	b
			SE	0.75		0.14		0.33		0.92	

† CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates; NF, no added fertilizer or manure.
‡ Yields with the same letter within each crop were not significantly different ($P \leq 0.05$).

served each year of the study in the soybean plots, no staining of the soybean was observed, so no reduction in the price premium for organic soybean was used in the economic analysis. However, some yield reduction may have occurred, particularly in 2002 when bean leaf beetle populations were near threshold levels for insecticide application, but no insecticide was applied. Soybean aphid (*Aphis glycines* Matsumura) populations exceeded threshold levels in 2003 and 2005 and were sprayed in the CNV treatments only. This may have lead to relative reductions in ORG soybean yield in those years.

Wheat yields were affected by system, fertility, and tillage ($P < 0.05$). Average wheat yield for the CNV CT C-S-W/A-A YF system was 0.6 to 1.5 Mg ha^{-1} higher than the wheat yields obtained under any other system except the CNV ST C-S-W/A-A YF system. The NF wheat yields were 0.3 to 0.8 Mg ha^{-1} less than YF yields. Average wheat yield for the best ORG treatment showed a 19% yield reduction compared to the best CNV treatment. Our study was unique in using spring wheat in an organic corn and soybean cropping system, while comparable studies used oat (*Avena sativa* L.) as the small grain crop (Porter et al., 2003; Delate and Cambardella, 2004). Porter et al. (2003) showed no significant difference between conventional and organic oat yields.

Alfalfa yields were affected by system, fertility, and system by fertility interaction ($P < 0.05$). In the CNV system, average alfalfa yield for the YF treatments was 2.7 Mg ha^{-1} higher than for the NF treatments. Alfalfa yield for the ORG CT C-S-W/A-A YF system was 2.4–2.6 Mg ha^{-1} lower than any of the CNV YF treatments, and although the ORG ST C-S-W/A-A YF average alfalfa yield was not significantly different from the CNV YF yields, poorer stand establishment was apparent for the ORG treatments in 2003 than for the CNV treatments (data not presented). This resulted in some ORG plots being replanted in 2004, and in significantly lower ORG YF yields than CNV YF yields that year (data not presented).

Significant yield trend by treatment interactions were observed for each of the crops during the 4-yr transition period (Table 5). For corn, the trend was affected by system ($P < 0.01$) with a significant downward trend in ORG corn yields. Soybean yield trend was affected by a system by rotation interaction ($P = 0.05$), with a significant upward trend in CNV C-S-W/A-A soybean yields. The CNV CT and CNV ST yield trends were significantly higher than for ORG CT and ORG ST soybean, so even though average soybean yields for CNV treatments were not significantly different from the top two ORG treatments they were diverging over the transition period. Wheat yield trend was affected by a system by tillage interaction ($P = 0.03$). None of the system by tillage trends was significantly different from zero; however, the ORG ST wheat yield trend was significantly lower than the trends for the other system by tillage interactions. Similarly, for alfalfa, trends were affected by fertility ($P = 0.02$), with the alfalfa yield trend for NF treatments significantly lower than the trend for YF treatments.

Total weed seed production in 2002 was relatively low, averaging 8000 total seeds m^{-2}, with no difference

Table 5. Yield trends for crops from 2002 to 2005.†

Treatment	Yield trend
	Mg ha^{-1} yr^{-1}
Corn	
System ($P = 0.0018$)	
CNV	−0.22a‡
ORG	−1.40b*
SE	0.383
Soybean	
System × rotation ($P = 0.0465$)	
CNV C-S	0.17a
CNV C-S-W/A-A	0.32a*
ORG C-S	−0.16b
ORG C-S-W/A-A	−0.23b
SE	0.098
Wheat	
System × tillage ($P = 0.0344$)	
CNV CT	0.50a
CNV ST	0.44a
ORG CT	0.31a
ORG ST	−0.21b
SE	0.285
Alfalfa	
Fertility ($P = 0.0212$)	
NF	−1.93b
YF	−0.60a
SE	0.697

* Significant at the 0.05 probability level.
† CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates; NF, no added fertilizer or manure.
‡ Yield trends with the same letter within each crop were not significantly different ($P = 0.05$).

between CNV and ORG ($P > 0.05$). This suggested that the weeds were evenly distributed across the plots at the beginning of the experiment. However, as years progressed total weed seed production increased considerably in ORG, averaging 12,000, 32,000, and 42,000 seeds m^{-2} in 2003, 2004, and 2005, respectively. The CNV seed production each year (5000, 5000, and 13,000 seeds m^{-2}, respectively) was lower ($P < 0.05$) compared to ORG. About 80% of all seeds were green foxtail [*Setaria viridis* (L.) Beauv.]. Neither tillage nor rotation affected total weed seed production in CNV, but both affected seed production in ORG (19,000 vs. 28,000 in CT vs. ST, and 18,000 vs. 36,000 in 4-yr vs. 2-yr rotations). No obvious effects occurred due to fertility management. The higher weed pressures that emerged in ORG treatments compared to the CNV treatments likely contributed to the observed reductions in corn and wheat yields and also to the significant diverging yield trends that occurred for ORG vs. CNV corn and soybean yields.

Net Present Values

Net present values for the complete rotations without organic price premiums were affected by system, tillage, rotation, and tillage by system interaction ($P < 0.05$). Although net present values ranged from \$337 ha^{-1} to \$787 ha^{-1} among the CNV treatments, no significant differences due to tillage, rotation, or fertility were detected (Table 6). Net present values were higher for the CNV CT C-S YF and CNV ST C-S YF treatments than any of the organic treatments when no organic price

Table 6. Net present value of net returns for treatments from years 2002 to 2005.†

System	Tillage	Rotation	Fertility	No premium		With premium	
				$ ha^{-1}			
CNV	CT	C-S	YF	787	a‡	787	ab
CNV	CT	C-S	NF	537	ab	537	ab
CNV	CT	C-S-W/A-A	YF	538	ab	538	ab
CNV	CT	C-S-W/A-A	NF	357	abc	357	b
CNV	ST	C-S	YF	703	ab	703	ab
CNV	ST	C-S	NF	530	ab	530	ab
CNV	ST	C-S-W/A-A	YF	502	ab	502	ab
CNV	ST	C-S-W/A-A	NF	337	abc	337	bc
ORG	CT	C-S	YF	95	bc	1029	a
ORG	CT	C-S	NF	−62	cd	624	ab
ORG	CT	C-S-W/A-A	YF	−5	c	567	ab
ORG	CT	C-S-W/A-A	NF	14	c	551	ab
ORG	ST	C-S	YF	−137	cde	500	ab
ORG	ST	C-S	NF	−131	cde	417	ab
ORG	ST	C-S-W/A-A	YF	−580	e	−331	d
ORG	ST	C-S-W/A-A	NF	−438	de	−145	cd
	SE	C-S (n = 8)§		48.4		55.2	
		C-S-W/A-A (n = 16)¶		34.8		40.7	

† CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates; NF, no added fertilizer or manure.
‡ Net present values with the same letter within each column were not significantly different ($P \leq 0.05$).
§ SE values represent standard errors for treatments that include a C-S rotation.
¶ SE values represent standard errors for treatments that include a C-S-W/A-A rotation.

premiums were included. The CNV CT C-S YF treatment produced the highest net present value at \$787 ha^{-1}, which exceeded the net present value for the best ORG treatment, ORG CT C-S YF, by \$692 ha^{-1}. Dobbs and Smolik (1996) also reported higher profitability for conventional cropping compared to an organic cropping system in eastern South Dakota when no organic price premiums were included. In contrast, Mahoney et al. (2004) found no significant differences in net returns between a 4-yr sequence organic system and four conventional systems including: high input and low input, 2-yr and 4-yr crop sequence systems in southwest Minnesota. However, in this study we included manure loading and hauling costs, which added \$41–58 ha^{-1} to operating costs for the ORG YF systems, whereas these costs were not included in the Mahoney et al. (2004) study. Mahoney et al. (2004) also analyzed a longer time period which may have allowed crop yields to recover after an initial decline during the transition period. Delate et al. (2003) also found no significant differences in net returns among two organic systems and a conventional corn–soybean system in Iowa without organic price premiums; however, their results were sensitive to the assumptions on manure handling costs. The Delate et al. (2003) results were attributable to better crop yield performance and lower production costs for the organic relative to the conventional systems. We observed significant corn yield declines and, in some cases, higher production costs for ORG treatments relative to CNV treatments.

When organic price premiums were included for the ORG treatments in 2004 and 2005, the net present values for 2002 to 2005 were affected by tillage, fertility, rotation, and tillage by system, and rotation by system interactions ($P < 0.05$). The ORG CT C-S YF treatment produced net present values \$672 to \$1361 ha^{-1} higher than the CNV CT C-S-W/A-A NF, CNV ST C-S-W/A-A NF, ORG ST C-S-W/A-A YF, and ORG ST C-S-W/A-A NF systems (Table 6). Although net present values for the ORG CT C-S YF treatment exceeded that for the CNV CT C-S YF treatment by \$242 ha^{-1}, the difference was not statistically significant. This largely reflected the high variability observed in the experimental data. In our analysis, net present values for ORG CT C-S YF treatment were not significantly different from the ORG CT C-S-W/A-A YF treatment, although other studies have suggested that longer rotations may provide higher net returns in organic systems (Hima et al., 2005). Delate et al. (2003) reported no significant difference in net returns for organic systems in a 3-yr compared to a 4-yr rotation, while Mahoney et al. (2004) reported that net returns for an organic system with a 4-yr rotation exceeded those from a 2-yr rotation in the absence of organic price premiums. Mahoney et al. (2004) also reported average net returns for an organic 4-yr rotation of corn–soybean–oat/alfalfa–alfalfa were significantly higher than for either a conventional 2-yr rotation of corn–soybean or a conventional 4-yr rotation even if organic price premiums were reduced to half of the historical levels. The longer time period of their analysis (10 yr) likely contributed to this result since organic price premiums were received in 8 of the 10 yr, while our analysis reflected a 4-yr period in which 2 yr received organic price premiums.

Particularly with organic systems, where substantial price premiums may be received beginning in the third year of transition from conventional systems, the entry point into the system can have a significant effect on net present values (Fig. 1). For this analysis, entry point refers to the crop grown in the first year of the study, which was the first transition year. Looking at the YF treatments only, net present values for each rotation entry point were affected by system, tillage, rotation, entry point, and interactions of tillage by system, rotation by system, entry point by tillage, entry point by rotation, entry point by tillage by system, and entry point by rotation by system. The ORG CT C-S treatment, starting with soybean in 2002 provided the highest net present value over the 4-yr transition period at

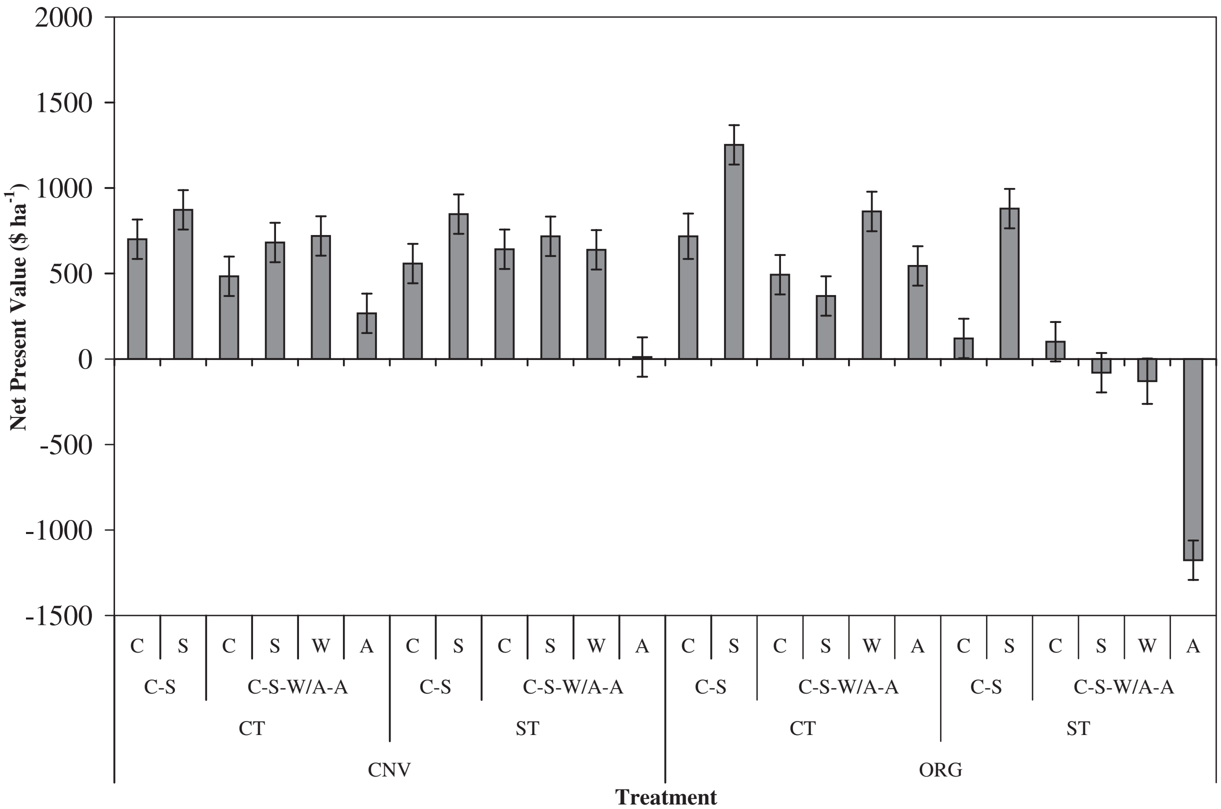

Fig. 1. Net returns including organic price premiums for each rotation entry point (YF treatments only) averaged over years 2002 to 2005. Rotation entry points denoted by the crop planted in 2002 as A, alfalfa; C, corn; S, soybean; W, spring wheat; CNV, conventional system; ORG, organic system; CT, conventional tillage; ST, strip tillage; C-S, corn–soybean rotation; C-S-W/A-A, corn–soybean–wheat/alfalfa–alfalfa rotation; YF, fertilizer or manure applied at recommended rates. Error bars represent standard errors.

$1253 ha^{-1}, which was $535 ha^{-1} higher than for that treatment with a corn entry point. Note that these results are somewhat sensitive to the length of time over which the comparisons are made, and over a longer time period, these differences should diminish. However, these short-term differences may be critical in determining economic survival during the transition years.

Within the C-S-W/A-A treatments, the alfalfa entry point generally provided the lowest net present value, since no alfalfa was harvested in 2002, providing no income for that year. This entry point was not expected to be one that most producers would consider. However, for the ORG CT C-S-W/A-A treatment, the alfalfa entry point was comparable to both the corn and soybean entry points, likely due to the benefit of alfalfa in providing N for the succeeding corn crop in ORG systems. The extremely poor performance of the alfalfa entry point in the ORG ST C-S-W/A-A treatment was due to the detrimental effect that volunteer alfalfa had on succeeding crops under limited tillage, thus making this option agronomically and economically unfavorable.

CONCLUSIONS

This study showed that, with typical organic price premiums, net present values for several organic cropping system alternatives during transition from a conventional system were competitive with conventional systems. However, without organic price premiums, there were significant reductions in short-term profitability for the organic systems that could act as a barrier to their adoption if organic price premiums were to decline. Although organic systems required less expenditures on purchased inputs, they required more fuel and labor, and higher investments in machinery ownership, which resulted in higher total production costs compared to conventional production systems. Organic production costs were sensitive to manure costs and could substantially increase or decrease depending on the cost of obtaining and handling manure. Organic systems had lower corn yields, and generally lower wheat and alfalfa yields compared to the highest yielding conventional systems; however, soybean yields for the highest-yielding organic systems were not significantly different from the highest-yielding conventional systems. This study also illustrated the importance of timing transition decisions to the appropriate entry point when short-term profitability is critical.

Within conventional systems, no significant differences in net present values were detected for tillage and rotation alternatives, suggesting no economic barriers to adoption of greater crop diversity and less tillage in the short term. Within organic systems, net present values were reduced for the combination of reduced tillage and increased crop diversity (ST C-S-W/A-A) compared to other combinations, and this was directly related to reductions in crop yields for this treatment. With the exception of this treatment, production costs were generally lower for systems with reduced tillage (ST vs. CT), and for systems that increased crop diversity (C-S-W/A-A vs. C-S). Within conventional systems, no significant difference in corn and soybean yields were detected for tillage and rotation alternatives, and the cost savings associated with these treatments did not lead to significant differences in profitability. Although crop yields were expected to be lower without the use of fertilizer or manure inputs, significant reductions generally were detected only for wheat and alfalfa over the 4-yr period, and this, combined with cost savings realized from fertilizer and manure inputs, resulted in no significant difference in profitability for the two fertility treatments during the transition from conventional high-input production.

An important determining factor for long-term economic viability is long-term productivity. In particular, weeds were increasing rapidly in ORG compared to CNV over 4 yr, which almost certainly impacted crop yields. The diverging trends in corn and soybean yields, with CNV systems showing higher yield trends compared to ORG systems, raises concern about the long-term viability of the ORG systems; however, this can only be determined by additional years of study.

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